State of California
Department of Fish and Wildlife

Memorandum

Date: March 5, 2018

To: Ramona Fernandez
Acting Deputy Director
Department of Parks and Recreation
Division of Boating and Waterways

From: Tina Bartlett
Acting Deputy Director
Ecosystem Conservation Division

Subject: Risk Assessment for alligatorweed (*Alternanthera philoxeroides*)

In response to the November 8, 2017, letter from the Division of Boating and Waterways requesting a risk assessment for a species of aquatic plant identified by the California Department of Parks and Recreation as potentially invasive, please find enclosed the California Department of Fish and Wildlife's (CDFW) risk assessment findings and determination regarding alligatorweed (*Alternanthera philoxeroides*). As required by the Harbors and Navigation Code (HNC), section 64.5, CDFW included in their assessment:

- Whether alligatorweed may obstruct navigation and recreational uses of waterways;
- Whether alligatorweed may cause environmental damage, including threats to the health and stability of fisheries, impairment to birds' access to waterways and nesting, roosting, and foraging areas, deterioration of water quality resulting from plant decay, and harm to native plants;
- Whether alligatorweed may cause harm to the state's economy, infrastructure, or other manmade facilities such as state water storage facilities and pumping operations, by increasing flood risk, threatening water supplies by blocking pumps, canals, and dams necessitating early control efforts; and
- Whether alligatorweed causes or is likely to cause any other harm to California's environment, economy, or human health or safety.

To ensure thorough consideration of the species' ecological characteristics and the specified impacts and threats, CDFW employed the U.S. Aquatic Weed Risk Assessment tool. As specified in HNC sec. 64.5, CDFW consulted with the California Department of Food and Agriculture, the California Department of Water Resources, the State Water Resources Control Board, the California Department of Pesticide Regulation, and the Office of Environmental Health Hazard Assessment to develop the risk assessment findings and determination.

As fully detailed within the enclosed risk assessment, CDFW concludes that alligatorweed should be considered an invasive aquatic plant that causes or is likely to cause economic or environmental harm or harm to human health in California. CDFW's risk assessment and determination of the previously requested native species, floating pennywort (*Hydrocotyle ranunculoides*), is forthcoming in March 2018.

If you have any questions regarding this risk assessment, or the other in process, please contact Ms. Martha Volkoff, Habitat Conservation Planning Branch, Invasive Species Program, at (916) 651-8658 or by email at martha.volkoff@wildlife.ca.gov.

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Aquatic Plant Risk Assessment

Alligatorweed, *Alternanthera philoxeroides* (Mart.) Griseb.

March 1, 2018

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INTRODUCTION

The California Department of Parks and Recreation's Division of Boating and Waterways (DBW) is the lead agency of the State for the purpose of cooperating with other state, local, and federal agencies in identifying, detecting, controlling, and administering programs to manage, control, and when feasible, eradicate invasive aquatic plants in the Sacramento-San Joaquin Delta, its tributaries, and the Suisun Marsh. Harbors and Navigation Code (HNC) §64.5 defines an "invasive aquatic plant" as an aquatic plant or algae species, including its seeds, fragments, and other biological materials capable of propagating that species, whose proliferation or dominant colonization of an area causes or is likely to cause economic or environmental harm or harm to human health. Per HNC §64.5, for aquatic plant species that DBW believes may be invasive and desires to manage, control, or eradicate, DBW shall request that the California Department of Fish and Wildlife (CDFW) conduct a risk assessment to determine if the species causes or is likely to cause economic or environmental harm or harm to human health. The risk assessment shall be documented in a way that clearly describes the severity and types of impacts caused or likely to be caused by a plant species determined to be an invasive aquatic plant. Within 60 days after completing the risk assessment, CDFW shall report its findings to DBW.

DETERMINATION

Per DBW's November 8, 2017, request, CDFW evaluated whether alligatorweed, *Alternanthera philoxeroides*, should be considered an invasive aquatic plant in California. To make the determination, CDFW selected a quantitative assessment tool that evaluated aspects of the species' ecology, reproductive potential, dispersal mechanisms, competitive ability, actual and potential impacts (including impacts to navigation and recreation, the environment, economy, and human health as specified in HNC §64.5), and resistance to management. Based on this evaluation and the findings contained herein, CDFW, in consultation with the California Department of Water Resources (DWR), State Water Resources Control Board, Department of Food and Agriculture (CDFA), Department of Pesticide Regulation, and Office of Environmental Health Hazard Assessment, and in concurrence with DWR, determines that alligatorweed is an invasive aquatic plant that causes, or is likely to cause, economic or environmental harm, or harm to human health in California.

CURRENT DISTRIBUTION

Alligatorweed is native to the Parana River region of South America (Vogt et al 1979; Sainty et al. 1998). However, it is now found in the southern United States and Mexico, Asia, Australia and New Zealand, Europe, Central America and the Caribbean, and outside of its native range in South America (Vogt et al. 1979; Julien et al. 1995; Bassett et al. 2010; EPPO 2016). It is listed as one of the top 20 most invasive weeds in Australia (Australian Weeds Committee 2012) and as a pest of economic importance by the European and Mediterranean Plant Protection Organization (EPPO 2017).

The first records of alligatorweed in the United States occurred between 1894-1897, in Alabama, Louisiana, and Florida (Maddox et al. 1971; Coulson 1977). By 1963, an estimated 162,000 acres were infested by alligatorweed in the southern United States (Coulson 1977). Today, alligatorweed occurs in the following states: AL, AR, CA, FL, GA, IL, KY, LA, MD, MS, NC, OK, SC, TN, TX, VA and Puerto Rico (Thayer and Pfingsten 2017; USDA 2017). In Southern California, alligatorweed has been present since 1946 and is currently established in Tulare, Kings, San Bernardino, Los Angeles, and Riverside counties (Calflora 2017). Control and eradication efforts have been in place for over 30 years for populations in Tulare, Kings, and Los Angeles counties (Bell and Lehman 2015). Alligatorweed was recently discovered at multiple locations (Montezuma Slough and under the Tower Bridge) in the Sacramento-San Joaquin River Delta, a vital ecosystem and water delivery hub for California. Alligatorweed is now found in the Bay Delta and Central Coast, Central Valley and Sierra Nevada, Deserts, and South Coast provinces, as classified by the State Wildlife Action Plan (CDFW 2015).

The California Department of Food and Agriculture has listed alligatorweed as a noxious weed (CDFA 2016) and it is categorized as having a "high" (severe) level of negative, ecological impacts in California (Cal-IPC 2006). Alligatorweed is identified as invasive or regulated as noxious, restricted, or prohibited in the states of AL, AZ, FL, GA, SC, TN, and TX (CISEH 2013; USDA 2017).

RISK ASSESSMENT

Alligatorweed was assessed using the U.S. Aquatic Weed Risk Assessment (USAqWRA) tool, which was modified for the U.S. by Gordon et al. (2012) from the New Zealand Aquatic WRA model (Champion and Clayton 2001). The USAqWRA functions as the aquatic alternative to the Australian WRA. While the Australian WRA is widely accepted and applied, it inaccurately classifies nearly all aquatic species as invasive, thus requiring modification for the accurate assessment of aquatic plants (Gordon and Gantz 2011). The USAqWRA has been tested for accuracy and validated under the environmental conditions of the U.S. and is the only assessment tool developed for the U.S. that maximizes accuracy for aquatic plants and incorporates all of the factors outlined in HNC §64.5.

The USAqWRA defines non-invaders as having no evidence of establishment outside of cultivation (in non-native ranges). Minor invaders are defined as species that have established in non-native ranges, but with no described ecological impacts. Major invaders are defined as having established in non-native ranges, and having documented, negative ecological impacts. Species are categorized using a scoring system of <31 (non-invaders), 31 – 39 (evaluate further), and >39 (major invaders). Gordon et al. (2012) determined that using the threshold score of 39 to distinguish major invaders from both minor and non-invaders maximized overall accuracy of the assessment tool at 91%.

CDFW conducted a thorough search of peer-reviewed journals and government publications to complete the assessment accurately. The resulting evaluation of alligatorweed invasiveness (Appendix A) produced a score of 74, predicting alligatorweed to be a "major invader" of the Sacramento-San Joaquin Delta. The findings using the USAqWRA model are summarized below, along with additional findings relevant to assessing potential impacts.

Ecology

Alligatorweed is an herbaceous, perennial species that colonizes both aquatic and terrestrial habitats. Mature plants are often rooted in moist soil and form dense, interwoven mats of stems that spread across the water. Alligatorweed growth is most prolific in subtropical to temperate climates with mild winters (Julien et al. 1995). During winter periods of cooler climate locations, much of the aboveground or emergent biomass is reduced, while most belowground or submerged biomass survives and supports regeneration (Shen et al. 2005; Geng et al. 2007; Pan et al. 2013).

Alligatorweed has simple or branched stems, either lacking hairs or having opposite, paired, lengthwise rows of hairs (DiTomaso and Healy 2003; Csurhes and Markula 2010). Stems grow flat or vertical, up to 1 m in height, and range in color from green to reddish pink (Zeiger 1967; Clements et al. 2011). Leaves are opposite, roughly equal at the node, and either sessile or with small, winged petioles (≤ 1 cm). Leaf blades (typically 4-11 cm long and 1-3 cm wide) are narrowly lanceolate to obovate, but do vary in shape (DiTomaso and Healy 2003; van Oosterhout 2007); they have a smooth, waxy surface and a complete margin. In the United States, plants flower from June through October (USAEWES 1981; DiTomaso and Healy 2003). Flowers are white, clover-like clusters that grow on 1-9 cm long stalks.

An extensive network of rhizomes with adventitious roots and stolons support alligatorweed's rapid growth and adaptability. Peak growth occurs in the spring, and the optimal temperature for growth ranges from 25-32 °C (77-90 °F) (Julien et al. 1995). According to lab studies, shoots emerged at temperatures between 10-40 °C (50-104 °F), with greatest emergence at 30 °C (86 °F); shoots did not emerge when temperatures remained at a constant 5 °C (41 °F) (Shen et al. 2005). Prolonged freezing or frost can kill leaves and stems, but submerged and buried parts typically survive (DiTomaso and Healy 2003). Plants may experience stress or population growth limitations at temperatures below 10 °C (50 °F) or above 33 °C (91 °F) (Julien et al. 1995).

Typically, alligatorweed grows in wet soils and shallow water, rarely beyond depths of 2 m (DiTomaso et al. 2013). It can occupy terrestrial habitats, but is primarily found near waterbodies (Coulson 1977). Alligatorweed expands out horizontally with stolons, creating dense, interwoven floating mats that extend out up to 15 m and can cover waterways (Zeiger 1967; Maddox et al. 1971; USAEWES 1981; Clements et al. 2011). Alligatorweed can occupy a variety of soil types and habitats, including ditches, pond edges, wetlands, marshes, crop fields, and other low-flow, aquatic environments (Sainty et al. 1998; van Oosterhout 2007). The pH tolerance is not well described, but alligatorweed has been observed growing in soil pH levels between 4.8 and 7.7 and in both neutral and alkaline conditions (pH 7.67±0.39) for the aquatic form (Chabreck 1972; van Oosterhout 2007; Csurhes and Markula 2010; Zuo et al. 2012). Alligatorweed can tolerate salinity levels ≤ 3.5 ppt in lentic waters and ≤ 10.5 ppt in lotic waters (Ensbey and van Oosterhout 2012). Chabreck (1972) documented alligatorweed in habitats along the Louisiana coast with water salinity levels ranging from 0 to 7.7 ppt.

There are two forms of alligatorweed, which vary by occupied habitat (Csurhes and Markula 2010; Zuo et al. 2012), and there is evidence for two, genetically-distinct biotypes, broad- and narrow-stemmed leaf forms (Kay and Haller 1982; Pan et al. 2013). In the aquatic environment, floating, emergent, and submerged stems are hollow and buoyant (Csurhes and Markula 2010). Terrestrial plants have solid stems and primarily grow along shores of waterbodies, in pastures or agricultural fields, and in wet soils (Julien et al. 1995; DiTomaso and Healy 2007; van Oosterhout 2007). Smaller leaves and fewer flowers are present on the terrestrial form, as well as shallower roots compared to floating plants (DiTomaso and Healy 2003; Csurhes and Markula 2010). In dry, terrestrial environments, alligatorweed forms large, tough, root-like rhizomes (Kay and Haller 1982) that may account for over 10% of total biomass (Geng et al. 2007). In moist soil conditions, belowground biomass may be up to 10 times that of aboveground biomass (Schooler et al. 2008). This belowground energy storage can sustain survival and support regeneration (Shen et al. 2005).

REPRODUCTIVE POTENTIAL

In its native range, alligatorweed spreads by sexual and vegetative reproduction (Sosa et al. 2008). In its non-native range, alligatorweed reproduces primarily vegetatively via stem buds and axillary root buds (USAEWES 1981; DiTomaso and Healy 2003; van Oosterhout 2007) and rarely produces viable seed (DiTomaso and Healy 2003; Csurhes and Markula 2010). When produced, a single seed is developed in the fruit. A fragment containing a single, intact node is all that is required for establishment in a new location (DiTomaso and Healy 2007; Peng et al. 2017). Alligatorweed rhizomes can persist through unfavorable conditions (e.g., low soil moisture, extreme temperatures) and initiate growth once conditions become favorable (Shen et al. 2005). Buried stem fragments can regenerate from depths of up to 30 cm (DiTomaso and Healy 2007) and may take between 4 to 17 days to sprout, depending on the number of nodes (Peng et al. 2017). Fragments collected from a California infestation were allowed to desiccate for 5-6 days; within 5 days of being placed in water, fragments sprouted new shoots (D. Kratville, CDFA, personal communication). Following chemical treatment-induced fragmentation, up to 80% of stem fragments remain viable for up to 315 days after treatment.

DISPERSAL MECHANISMS

Initially thought to have spread from its native range through ship ballast water (Zeiger 1967), current spread is likely due to fragmentation or dislodged floating mats, dispersal on conveyances (e.g., boats), flooding, and accidental or intentional domestic cultivations (Sainty et al. 1998; van Oosterhout 2007; Burgin et al. 2010; Australian Weeds Committee 2012). Early infestations in Southern California were spread by the transportation of alligatorweed-infested soils for use in other locations (Hill and Donley 1973). Once established in aquatic habitats, fragments can easily break off and be transported downstream to colonize new areas (Maddox et al. 1971; Dugdale et al. 2010). Because fragmentation occurs easily, primary dispersal methods include mechanical removal efforts and other human disturbances (e.g., damage by watercraft) (Sainty et al. 1998; Pan et al. 2013). Intentional plantings can be a dispersal method, as in Australia, where alligatorweed was mistaken for sessile joy weed (*Alternanthera sessilis*) and planted in yards (Australian Weeds Committee 2012; EPPO 2016).

Competitive Ability

New plants are highly competitive, grow quickly, and tolerate a variety of temperatures and habitats (Maddox et al. 1971; DiTomaso and Healy 2003; Csurhes and Markula 2010). The ability to grow on land and in water is a key advantage of alligatorweed over plants with narrower niches (USAEWES 1981), yet, the aquatic form of alligatorweed poses the greater invasion potential compared to the terrestrial form (Zuo et al. 2012). In a small, high nutrient urban pond in Australia, Clements et al. (2011) observed a 200% increase in area covered in the first year of an alligatorweed infestation. Despite low genetic diversity in non-native habitats, alligatorweed has high phenotypic plasticity (Chen et al. 2013; Geng et al. 2016), enabling it to be a successful invader (Wu et al. 2016), with different growth forms occupying different niches (Shen et al. 2005). Alligatorweed is fairly resistant to flooding (Shen et al. 2005; Chen et al. 2013), but less tolerant of drought conditions (Shen et al. 2005). While growth rates are reduced, alligatorweed fragments can survive waterlogging for up to 60 days (Chen et al. 2013).

Dense infestations can result in a monoculture (Spencer and Coulson 1976), as few plants can successfully compete with alligatorweed (Maddox et al. 1971). Floating mats of alligatorweed can outcompete other floating-leaved aquatic species as well as restrict sunlight penetration into the water column, killing submerged plants (Lynch et al. 1947; USAEWES 1981). However, the plant is often found in conjunction with other invasive plants, such as waterprimroses (*Ludwigia* spp.) and water hyacinth (*Eichhornia crassipes*) (Coulson 1977). The terrestrial form of alligatorweed coexists with a greater number of other plant species than its aquatic form (Zuo et al. 2012).

Realized and Potential Impacts

Impacts associated with the presence and spread of alligatorweed are documented for locations within the United States, as well as for a number of other countries. Alligatorweed is often found growing with invasive water hyacinth (Spencer and Coulson 1976; USAEWES 1981), and although competition between the species may occur, alligatorweed can harbor and facilitate the growth of water hyacinth (Wundrow et al. 2012), which also significantly impacts each of the impact categories below.

Obstruction of Navigation and Recreation

The U.S. Army Corps of Engineers (USACE) recognized the negative impacts of alligatorweed on navigable waterways of the United States in the early- to mid-1900s (Zieger 1967; Coulson 1977; Gunkel and Barko 1998). Alligatorweed clogs waterways, restricting navigation and boat access and damages propellers (Coulson 1977; USAEWES 1981). Dense mats of alligatorweed along the banks of rivers, lakes, and streams can limit access for anglers, boaters, and other water users (Spencer and Coulson 1976). Alligatorweed mats can become so dense they are capable of supporting the weight of a human (DiTomaso et al. 2003).

Environmental Effects

Water quality – Dense mats formed by alligatorweed are widely recognized to negatively impact water quality (DiTomaso and Healy 2007; van Oosterhout 2007; Australian Weeds Committee 2012). By forming dense mats on the surface of the water, alligatorweed reduces sunlight penetration into the water column, creating low oxygen as well as anoxic conditions (Spencer and Coulson 1976; Coulson 1977; DiTomaso and Healy 2007; Harms 2017).

Native plants – Alligatorweed outcompetes native vegetation and reduces biodiversity by displacing other species (Maddox et al. 1971; DiTomaso and Healy 2003; Chatterjee and Dewanji 2014). Alligatorweed can outcompete and displace submerged, free-floating, and emergent vegetation, but free-floating species are less impacted and their growth may be facilitated by the presence of alligatorweed (Wundrow et al. 2012; Chatterjee and Dewanji 2014). Chatterjee and Dewanji (2014) found that with increasing (30-100%) percent cover of alligatorweed in pond habitats of India, there was a reduction in plant species diversity and evenness, with greater losses as alligatorweed cover increased. Moreover, as alligatorweed percent cover increased, native plant species richness decreased (Chatterjee and Dewanji 2014). Similar trends were noted in China, where increasing percent cover of alligatorweed (>20-100%) in terrestrial habitats was associated with reductions in species diversity (Wu et al. 2016). In contrast, smaller scale infestations, increasing in alligatorweed cover from 0% to 20%, tended to be associated with an increase in species diversity (Wu et al. 2016; Wu et al. 2017).

Birds and waterfowl – Multiple trophic levels can be impacted by the introduction of an invasive species and subsequent shifts in food-web dynamics (Villamagna and Murphy 2010). Although relevant information specific to alligatorweed is limited, large mats of invasive vegetation, such as those created by alligatorweed infestations, can reduce invertebrate abundances and food plants for waterfowl, restrict access to nesting areas, and reduce available habitat (Lynch et al. 1947; Allen et al. 2007; Pan et al. 2010; Kaufman and Kaufman 2013). Alligatorweed restricts light penetration to submerged vegetation such as native pondweeds (van Oosterhout 2007), which are important food sources for migratory waterfowl (Wersal and Getsinger 2014). Alligatorweed is not considered an important food source for waterfowl (Holm et al. 1997; Nelms et al. 2007).

Health and stability of fisheries – No studies directly examined the positive or negative effects of alligatorweed on the stability of fisheries. However, decomposition of dense alligatorweed infestations reduces dissolved oxygen levels, which can be harmful to a variety of fish species (Lynch et al. 1947; Clark 1969; Maddox et al. 1971), particularly juvenile anadromous and cold-water species (Alabaster 1988, 1989). Conversely, alligatorweed may provide habitat for small, prey fish (USAEWES 1981) or for predatory fishes (Clark 1969). In a wetland in China, alligatorweed supported a lower abundance of native invertebrates than did the native plant community (Pan et al. 2010), but this trend was not consistent with observations from an alligatorweed-infested lake in New Zealand (Bassett et al. 2012).

Economic, Infrastructure, or Man-made Facilities

Dense growth of alligatorweed in waterways and canals can cause substantial harm to infrastructure and other man-made facilities (Sainty et al. 1998; van Oosterhout 2007). Alligatorweed may reduce crop yields (Julien et al. 1995; van Oosterhout 2007) by competing with and contaminating crops. This could result in costly control or eradication efforts (Sainty et al. 1998). In Australia, it has invaded and caused damage to rice, wheat, and other agricultural crops (van Oosterhout 2007), and work to remove or control alligatorweed spread has cost millions of US dollars (Australian Weeds Committee 2012). In China, alligatorweed has invaded gardens, sweet potato crops, and citrus groves, with control efforts costing $72 million (USD)/year on average (Ruolan 2003; Liu and Diamond 2005). Alligatorweed may also cause photosensitivity in grazing cattle (Bourke and Rayward 2003). In some cases, alligatorweed may reduce the commercial and/or aesthetic values of waterfront properties (USAEWES 1981). In addition to direct economic impacts, the rapid spread and dense growth of alligatorweed can clog drainages and increase flooding risk (Coulson 1977; Csurhes and Markula 2010).

Human Health

While alligatorweed is not poisonous/toxic to humans, impacts to water quality resulting from dense alligatorweed infestations can be harmful to humans. Dense mats of alligatorweed can provide mosquito breeding habitat; therefore, potentially harboring mosquito-vectored diseases (Clark 1969; Coulson 1977; DiTomaso et al. 2013). Alligatorweed may increase the risk of drowning and entanglement by swimmers (Spencer and Coulson 1976; Buckingham 2002).

RESISTANCE TO MANAGEMENT

Given its long withstanding presence as a noxious weed, a variety of management actions have been utilized to control alligatorweed, including mechanical, chemical, and biological methods (USAEWES 1981; Sainty et al. 1998).

Biological control methods for alligatorweed have been used for many years, with varying degrees of success in the United States and other countries (Zeiger 1967; USAEWES 1988; Buckingham 1996; Bassett et al. 2012; Winston et al. 2014). The primary invertebrate species used for biocontrol are alligatorweed flea beetle (*Agasicle hygrophila*), alligatorweed stem borer (*Arcola malloi*; formerly *Vogtia malloi*), and alligatorweed thrips (*Amynothrips andersoni*), with alligatorweed flea beetles being the most widely used and successful in aquatic environments (Maddox et al. 1971; Coulson 1977). In California, all three biocontrol agents were released in infested areas of Los Angeles County in the mid-1960s, but populations failed to establish (Goeden and Ricker 1971; Coulson 1977; USAEWES 1988) or were destroyed by flooding (Goeden and Ricker 1971). Successful biological control of alligatorweed did or continues to occur in some southern states, including Louisiana, Florida, Mississippi, and Georgia, thereby eliminating the need to use chemical treatments (Coulson 1977; USAEWES 1988; Harms and Shearer 2017).

The USACE continues to distribute alligatorweed flea beetles for biocontrol, but they do not affect the terrestrial form and have a more restricted range than alligatorweed, with the beetles requiring winter temperatures of at least 11.1 °C (52 °F) (Harms 2017). These factors (i.e., temperature, aquatic vs.

terrestrial growth forms) may limit its success as a biocontrol agent in certain areas (Julien et al. 1995; USAEWES 1988), particularly those with extreme summer or winter temperatures (Spencer and Coulson 1976; Sainty et al. 1998) and water fluctuations (Coulson 1977; USAEWES 1988).

In field studies conducted in Louisiana and Mississippi, leaf damage (percent of total leaf area damaged) from alligatorweed flea beetles was 7 ± 3 % (mean ± SE) in northern sites (average winter temperature 8.6 °C (47.5 °F)) compared to 21 ± 2 % (mean ± SE) in southern sites (average winter temperature 11.6 °C (52.9 °F)), where beetles were able to overwinter and cause early-season damage to alligatorweed (Harms and Shearer 2017). While biological control methods for alligatorweed and other invasive weeds can reduce the competitive advantage of invasive species, the degree of achieved control varies (Maddox et al. 1971; USAEWES 1981; Harms 2017).

Mechanical removal of alligatorweed does occur, but the risk of spread due to fragmentation and downstream movement requires additional precautions (Maddox et al. 1971; Spencer and Coulson 1976; DiTomaso et al. 2013). If all fragments are removed and/or contained, pulling, cutting, hand removal, mechanical harvesting, and disking are effective for clearing alligatorweed (USAEWES 1981; DiTomaso et al. 2013). In Australia, extensive physical removal of alligatorweed patches was successful, but required frequent follow-up and labor-intensive effort (4.5 to 10.5 person hours/m^2) (Clements et al. 2014). Due to the risk of fragmentation and further spread, Sainty et al. (1998) suggests that mechanical removal efforts be restricted to small, terrestrial invasions. Particular care should be taken when removing belowground biomass, which, if not entirely removed, quickly regrows (Clements et al. 2014). Shen et al. (2005) noted that summer plowing to pull alligatorweed rhizomes to the surface and promote desiccation may reduce shoot emergence. Alligatorweed is tolerant of shade; therefore, weed cloth or cover treatments are likely ineffective (Shen et al. 2005; Bassett et al. 2011).

Chemical control options for alligatorweed often require multiple treatments, but can be an effective control measure (USAEWES 1981; DiTomaso et al. 2013; Clements et al. 2014; Taggart et al. 2015). DiTomaso et al. (2013) offer multiple treatment options, including glyphosate, 2,4-D, triclopyr, and imazapyr. Greater control may be achieved by the integrated use of different herbicides, depending on the timing of application, frequency of re-treatment, water depth, and habitat (aquatic or terrestrial) (McGilvrey and Steenis 1965; Weldon and Blackburn 1969; Allen et al. 2007; Cox et al. 2014).

When comparing selective (triclopyr) and non-selective (glyphosate) herbicide treatments, dicot-selective formulas resulted in greater reductions of alligatorweed biomass and increased growth of monocot competitors in moist soil conditions (Schooler et al. 2008). During lab studies, glyphosate, imazapyr, triclopyr, and 2,4-D applied at the maximum label rate resulted in percent biomass reductions of 95%, 99%, 95%, and 94%, respectively, by 12 weeks after treatment (Cox et al. 2014). In managed marshes of southeastern Alabama, chemical treatments (triclopyr amine and imazapyr) proved successful where mechanical (mowing, disking, and burning) and biological (alligatorweed flea beetle) methods had limited success (Allen et al. 2007). Several of the suggested treatments (glyphosate, 2,4-D, triclopyr, and imazapyr) are registered for use in California and are currently approved for use under DBW's aquatic vegetation treatment programs.

As observed with mechanical control, damage from chemical treatments causes stem fragmentation, with up to 80% of stem fragments remaining viable after treatment (Dugdale et al. 2010). Clements et al. (2017) found that while glyphosate treatments produced 72% fewer stem fragments than metsulfuron and imazapyr treatments, metsulfuron and imazapyr provided greater duration of control (reduction of aboveground biomass). The average time to sprouting for post-treatment, viable stem fragments was 269, 253, and 315 days after treatment, respectively (Clements et al. 2017). In Australia, an infestation thought to have been eradicated showed regrowth 10 years later, emphasizing the need for continued, regular monitoring for years after treatment (van Oosterhout 2007).

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Species: Alligatorweed, *Alternanthera philoxeroides*					
	Question - USAqWRA	**Score and guidance – USAqWRA**	**Score**	**Justification**	**Reference**
1.1	Temperature tolerance	**(0-3)** Score 3 if maintains photosynthetic tissue and summer growth form throughout winter, 2 if dies back to tuber/bulb/rhizome (or similar structure) during winter, 1 if adult plants completely die but viable seeds remain. Use a climate matching tool if direct evidence is not available. Default = 1 for annual species.	2	Most aboveground biomass dies back in cooler climate winters; emergence begins when spring temperatures reach 10 °C	Sainty et al. 1998; Shen et al. 2005
1.2	Range of habitat	**(1-3)** Score 3 if able to grow from water to dry land, 2 if water to wetland, or from shallow to deep (>5 m) water, 1 narrow range. Default = 1 if no information is available; 2 for free-floating plants, unless more information is available.	3	Typically occupies shallow aquatic habitats, but also grows in terrestrial areas.	Julien et al. 1995; DiTomaso and Healy 2003; Shen et al. 2005
1.3	Water/ substrate type tolerance	**(1-2)** Score 2 if tolerant of sandy to muddy (or peaty) substrate, or oligotrophic to eutrophic waters, 1 if restricted by either. Default = 1 if no information is available.	2	Can grow in soil types ranging from sand to heavy clay	van Oosterhout 2007
1.4	Water clarity tolerance	**(0-1)** Score 1 if unaffected by water clarity (i.e. floating or emergent, or submergent species tolerant of very low light levels, such as *Myriophyllum spicatum* and *Hydrilla verticillata*), 0 if affected by water clarity.	1	Emergent growth and floating mats are tolerant of many conditions; can grow on land	DiTomaso and Healy 2003
1.5	Salinity tolerance	**(0-1)** Score 1 if species can tolerate saline conditions, 0 if not. Habitat information can be used to determine a score of 0 if species is only found to occur in freshwater habitats.	1	Can tolerate salinity levels ≤10.5 ppt; may survive in seawater for days and be transported to new habitats	Chabreck 1972; Sainty et al. 1998; Ensbey and van Oosterhout 2012
1.6	pH tolerance	**(0-1)** Score 1 if tolerant of both acidic and basic pH or no information is available, 0 if restricted to neutral, basic, or acidic pH.	1	pH tolerance not well described in the literature; grows in soil pH of 4.8-7.7; aquatic form grows in neutral or alkaline conditions	Chabreck 1972; van Oosterhout 2007; Zuo et al. 2012
1.7	Water level fluctuation - Tolerates periodic flooding/ drying	**(0-3)** Score 3 for species which have evidence of tolerating periodic flooding/drying with a specified time period longer than 1 month (e.g., "months"; "X months", "winter flooding"), 2 for evidence of tolerance of flooding/drying over a period of days/a couple of weeks, 1 for species that die back during periods of flooding/drying, and 0 for species that do not tolerate flooding/drying. Do not score if there is no information available.	3	Fragments tolerate flooding or waterlogging for 15-60 days; less resistant to drought conditions, but can survive and regrow when conditions are again favorable	Shen et al. 2005; Chen et al. 2013

Species: Alligatorweed, *Alternanthera philoxeroides*					
	Question - USAqWRA	**Score and guidance – USAqWRA**	**Score**	**Justification**	**Reference**
2.1	Lotic - Rivers, streams, drains, or other flowing waters, including their margins	**(0-3)** Score 3 if major weed (reaches high density and dominates plant community), 2 if minor weed (common, but rarely or never dominant), 1 if present but not weedy, 0 if absent.	3	Rapid growth can become dominant in streams, rivers, and drainages	Coulson 1977; DiTomaso and Healy 2003
2.2	Lentic - Ponds, lakes and other standing waters, including their margins	**(0-3)** Score 3 if major weed (reaches high density and dominates plant community), 2 if minor weed (common, but rarely or never dominant), 1 if present but not weedy, 0 if absent.	3	Growth on shoreline and shallow water can establish monotypic stands	Zeiger 1967; Maddox et al. 1971; Spencer and Coulson 1976; Coulson 1977
2.3	Swamp, marsh, bog, or other wet areas not covered by 2.1 or 2.2	**(0-3)** Score 3 if major weed (reaches high density and dominates plant community), 2 if minor weed, 1 if present but not weedy, 0 if absent.	3	Invades agricultural areas, drainages, and marsh habitats	Ziegler 1967; Julien et al. 1995; Australian Weeds Committee 2012
2.4	Establishment – into existing vegetation	**(-5, -3, 0)** Score 0 if able to invade unmodified vegetation, -3 if the species can only colonize certain types of vegetation (e.g., turf-forming shoreline vegetation), -5 if there is no evidence that the species can move into intact vegetation. Default = 0 if there is evidence of establishment, but no specific information about level of invasion into existing vegetation and/or type of vegetation being invaded. Default = -3 for species that have not naturalized outside of their native range.	0	Can invade agricultural crops and other established vegetation	Julien et al. 1995; van Oosterhout 2007; EPPO 2016
2.5	Establishment – into disturbed vegetation	**(0, 1, 5)** Score 5 if able to aggressively colonize following vegetation clearance, newly constructed waterbodies or nutrient enrichment, 1 if the species grows in disturbed areas, but there is no other information, 0 if there is no evidence of establishment in disturbed areas. Information from either the native or introduced range may be used to answer this question. Default = 1 for no information.	5	Thrives under high nutrient conditions and readily invades disturbed sites	DiTomaso and Healy 2003; Csurhes and Markula 2010
3.1	Competition – between growth form	**(0, 1, 2)** Score 2 if species forms dense stands that are documented to displace other growth forms (submerged, floating, emergent), 1 if some suppression, 0 if no displacement. Default = 0 if species has been in the trade globally for >30 years and there is no information about the species displacing other growth forms.	2	Displaces submerged and floating vegetation	Maddox et al. 1971; DiTomaso and Healy 2003 Chatterjee and Dewanji 2014

Species: Alligatorweed, *Alternanthera philoxeroides*					
	Question - USAqWRA	**Score and guidance – USAqWRA**	**Score**	**Justification**	**Reference**
4.1	Dispersal outside catchment by natural agents (e.g. birds, wind)	**(0, 1, 3, 5)** Score 5 if species (including seeds, rhizomes, fragments etc.) well adapted, and likely to be frequently dispersed, by natural agents, 3 if transport by natural agents is possible but uncommon, 1 if propagule could be spread in bird crop, 0 if no, or extremely low, likelihood of dispersal by natural agents (e.g., *Hydrilla* is scored 1 because its turions can survive passage through duck guts, an agent of dispersal, but this is believed to happen rarely).	5	Fragments are readily transported by water flow; flooding can be a source of dispersal	Lynch et al. 1947
4.2	Dispersal outside catchment by accidental human activity	**(1, 2, 3)** Score 3 if major pathway, seeds/fragments adapted for easy transportation (e.g., via boat/trailer, fishing gear), 2 if the species is a floating plant or a macrophyte, but no explicit mention of high spread in the literature, 1 not mentioned, not likely to be spread by human activity based on growth form and life history. Default = 1 if no information is available.	3	Human disturbance can facilitate rapid spread due to fragmentation; fragments can be moved via boats, substrate movement	Zeiger 1967; Sainty et al. 1998; Burgin et al. 2010; Australian Weeds Committee 2012
4.3	Dispersal outside catchment by deliberate introduction	**(0-1)** Score 1 if species is desirable to humans (e.g., or used for medicinal, food, ornamental, restoration, etc. purposes in the U.S. or elsewhere). If species is not used or no information exists, score should be 0.	0	Not commonly planted; occasionally mistaken for sessile joyweed used for domestic cultivation	Van Oosterhout 2007; Burgin et al. 2010; Australian Weeds Committee 2012; EPPO 2016
4.4	Effective spread within waterbody/ catchment	**(0-1)** Score 1 for extensive spread within a waterbody or among waterbodies, 0 for no spread. Occurrence along streams or riverbanks or in rivers can be used as evidence, as well as evidence of water dispersal. Do not answer if no information is available.	1	Occurs along streambanks and can colonize land; rapid growth; fragments easily, which are often viable	Maddox et al. 1971; Coulson 1977; Dugdale et al. 2010; Clements et al. 2011
5.1	Generation time (time between germination of an individual and the production of living offspring, not seeds or other dormant structures)	**(1, 2, 3)** Score 3 if rapid (reproduction in first year and >1 generation/year), 2 if annual or produces one generation every year including the first year, 1 if not reproductively mature in the first year. Default = 1 if no information is available.	3	Primarily vegetative reproduction, with fragments capable of sprouting within 5 days	USAEWES 1981; van Oosterhout 2007; DiTomaso et al. 2013; Peng et al. 2017

Species: Alligatorweed, ***Alternanthera philoxeroides***					
	Question - USAqWRA	**Score and guidance – USAqWRA**	**Score**	**Justification**	**Reference**
6.1	Seeding ability - Quantity	**(0-3)** Score 3 if >1000 seeds/plant/year, 2 100-1000, 1 <100 and/or evidence that seed are produced (in native or introduced range), 0 if seed not produced.	0	One seed per flower, but rarely produces viable seed in non-native range	DiTomaso and Healy 2003; van Oosterhout 2007
6.2	Seeding ability - Viability/ persistence	**(0-2)** Score 2 if highly viable for >3 years, 1 low viability or evidence of seed production with no information on viability, 0 no viable seeds.	0	Does not produce viable seed in non-native range or rarely viable	DiTomaso and Healy 2003; Sosa et al. 2008
7.1	Vegetative reproduction	**(0, 1, 3, 5)** Score 5 for naturally fragmenting from rhizomes, stolons, or other vegetative growth into tissue capable of producing new colonies (e.g., *Egeria densa*), 3 if produces rhizomes/stolons, but there is no other information about the formation of new colonies elsewhere, 1 for clump-forming by vegetative spread, 0 for no vegetative spread.	5	Fragments with node(s) (and potentially without) can produce new colonies	Maddox et al. 1971; DiTomaso and Healy 2007; Peng et al. 2017
8.1	Physical-water use, recreation	**(0-2)** Score 2 for major nuisance, 1 for minor nuisance. Default = 0 if the species has not naturalized outside of its native range. If there is a reasonable amount of information about the species and it has naturalized outside of its native range, default = 0.	2	Clogs waterways and impedes recreation, such as fishing, swimming, and waterskiing	Ziegler 1967; Coulson 1977; van Oosterhout 2007
8.2	Physical – access	**(0-2)** Score 2 for major nuisance, 1 for minor nuisance. Default = 0 if the species has not naturalized outside of its native range. If there is a reasonable amount of information about the species and it has naturalized outside of its native range, default = 0.	2	Impedes navigation and can restrict dock and shoreline access for boating and recreation	Spencer and Coulson 1976; Coulson 1977
8.3	Physical - water flow, power generation	**(0-2)** Score 2 for major nuisance, 1 for minor nuisance. Default = 0 if the species has not naturalized outside of its native range. If there is a reasonable amount of information about the species and it has naturalized outside of its native range, default = 0.	2	Large, dense mats reduce water flows and increase sedimentation	Coulson 1977; van Oosterhout 2007
8.4	Physical - irrigation, flood control	**(0-2)** Score 2 for major nuisance, 1 for minor nuisance. Default = 0 if the species has not naturalized outside of its native range. If there is a reasonable amount of information about the species and it has naturalized outside of its native range, default = 0.	2	Extensive growth clogs drainages/ canals and increases flood risk	Zeiger 1967; Coulson 1977

Species: Alligatorweed, *Alternanthera philoxeroides*					
	Question - USAqWRA	**Score and guidance – USAqWRA**	**Score**	**Justification**	**Reference**
8.5	Aesthetic - visual, olfactory	**(0-2)** Score 2 for both visual and odor problems, 1 either, 0 neither or no mention of these impacts. Surface matting of macrophytes scores 1 for visual impact.	1	Reduces the aesthetic value of near shore properties	USAEWES 1981
9.1	Reduces biodiversity	**(0, 1, 3, 5)** Score 5 for extensive monospecific stands, 3 for species that become dominant, 1 for small monospecific stands, and 0 if species does not become dominant over other species. Default = 0 for this question if species has been in the trade globally for >30 years and no information is found or if the species is not naturalized outside of its native range.	3	Increased alligatorweed cover reduces native species diversity and richness with; can create monotypic stands	Spencer and Coulson 1976; USAEWES 1981; Wundrow et al. 2012; Chatterjee and Dewanji 2014
9.2	Reduces water quality	**(0, 1, 3)** Score 3 if evidence that this species causes deoxygenation (e.g., through extensive growth in shallow water) or other water quality loss (e.g., loss of water clarity because of high decomposition rates continuously during the growing season), 1 if deoxygenation or other water quality loss is likely based on seasonal growth cycles (e.g., macrophyte that gets to high density and dies off at end of summer), 0 otherwise. Default = 0 for this question if species has been in the trade globally for >30 years and no information is found or if the species is not naturalized outside of its native range.	3	Limits sunlight penetration and can lead to anoxic conditions; high decomposition rates	USAEWES 1981; DiTomaso and Healy 2007; Bassett et al. 2010
9.3	Negatively affects physical processes	**(0, 2)** Score 2 if species alters hydrology (e.g., increases the chance of flooding) or substrate stability (e.g., increases amount of sediment erosion or deposition), or other physical processes, 0 if the species has no history of modifying physical processes. Default = 0 for this question if species has been in the trade globally for >30 years and no information is found or if the species is not naturalized outside of its native range.	2	Extensive growth and sedimentation can lead to increased flooding potential	Coulson 1977; van Oosterhout 2007
10.1	Human health impairment (e.g. drowning, poisonous, mosquito habitat)	**(0-2)** Score 1 for one effect, 2 for 2 or more effects.	2	Provides mosquito habitat, which can serve as vectors for mosquito-related diseases; can increase risk of drowning	Coulson 1977; CAST 2014

Species: Alligatorweed, *Alternanthera philoxeroides*					
	Question - USAqWRA	**Score and guidance – USAqWRA**	**Score**	**Justification**	**Reference**
10.2	Weed of agriculture, including crops, livestock and aquaculture	**(0-1)** Score 1 if a problem agricultural weed, 0 if no evidence that it is an agricultural weed, or if evidence states that species is in agricultural areas but not problematic.	1	Negative impacts (i.e., yield reduction) to rice, corn, wheat and other crops	Yi 1992; Zhang et al. 2004; Liu and Diamond 2005; van Oosterhout 2007
11.1	Management - Ease of management implementation	**(0-2)** Score 2 if accessibility to weed is difficult, e.g. dense tall impenetrable growths or growing in habitats that are difficult to access by roads or waterways (e.g., swamps). For species that have naturalized outside of their native range, default = 0-2 based upon evidence about habitat and/or growth form if there is no direct evidence from the literature. Default = 0 if species has not naturalized outside of its native range and has been in the trade globally for >30 years.	1	Dense growth capable of limiting access for control efforts and application; effective herbicide treatment requires complete stem coverage	Coulson 1977; Julien et al. 1995; Sainty et al. 1998; van Oosterhout 2007; Dugdale et al. 2010
11.2	Management - Recognition of management problem	**(0-1)** Score 1 if difficult to assess weed, e.g., submerged; looks like another species. For species that have naturalized outside of their native range, default to a score between 0-1 based upon growth form evidence if there is no direct evidence from the literature. Default = 0 if species has not naturalized outside of its native range and has been in the trade globally for >30 years.	0	Emergent and terrestrial growth easy to assess	Julien et al. 1995; DiTomaso and Healy 2003
11.3	Management - Scope of control methods	**(0, 1, 2)** Score 2 if no control method, 1 if only one control option. If species has naturalized outside of its native range, and there is no direct evidence for either 11.1 or 11.2, do not answer if there is no information. If there is direct evidence for 11.1 and/or 11.2, default to 0 if there is no information for this question. Default = 0 if species has not naturalized outside of its native range and has been in the trade globally for >30 years.	0	Chemical, biological, and mechanical options exist, with varying degrees of success	Zeiger 1967; USAEWES 1981; USAEWES 1988; Sainty 1998; Winston et al. 2014

Species: Alligatorweed, *Alternanthera philoxeroides*					
	Question - USAqWRA	**Score and guidance – USAqWRA**	**Score**	**Justification**	**Reference**
11.4	Management - Control method suitability	**(0-1)** Score 1 if control method not always acceptable, e.g., grass carp, unregistered herbicide. If species has naturalized outside of its native range, and there is no direct evidence for either 11.1 or 11.2, do not answer if there is no information. If there is direct evidence for 11.1 and/or 11.2, default to 0 if there is no information for this question. Default = 0 if species has not naturalized outside of its native range and has been in the trade globally for >30 years.	0	Mechanical control can increase fragmentation; biological (insect) control is limited geographically; chemical control is an option	USAEWES 1988; Sainty et al. 1998; Winston et al. 2014
11.5	Management - Effectiveness of control	**(0, 1, 2)** Score 2 if ineffective, 1 if partial control. If species has naturalized outside of its native range, and there is no direct evidence for either 11.1 or 11.2, do not answer if there is no information. If there is direct evidence for 11.1 and/or 11.2, default to 0 if there is no information for this question. Default = 0 if species has not naturalized outside of its native range and has been in the trade globally for >30 years.	1	Partial control possible within 2-5 years; herbicides vary in efficacy and fragments remain viable for nearly 1 year after treatment, biological control limited, and mechanical control successes for small projects	Maddox et al. 1971; Sainty 1998; Allen et al. 2007; DiTomaso et al. 2013; Clements et al. 2014; Winston et al. 2014; Clements et al. 2017
11.6	Management - Duration of control	**(0, 1, 2)** Score 2 if no control, 1 if control for 3+ months. If species has naturalized outside of its native range, and there is no direct evidence for either 11.1 or 11.2, do not answer if there is no information. If there is direct evidence for 11.1 and/or 11.2, default to 0 if there is no information for this question. Default = 0 if species has not naturalized outside of its native range and has been in the trade globally for >30 years.	1	Partial control from months to years	Coulson 1977; Allen et al. 2007; Schooler et al. 2008
12.1	Problem in other countries	**(0, 1, 3, 4, 5)** Score 5 if species has been reported to be a widespread problem (i.e., a harmful weed in many other countries), 4 if species has been reported to be a harmful weed in 5 or fewer countries, 3 if species has been reported to be a widespread adventive (but not a harmful weed) in many other countries, 1 if species has been reported to be adventive in 5 or fewer countries, 0 if not adventive elsewhere.	5	Present as a harmful weed in over 30 countries; widespread invader in Australia	Julien et al. 1995; Liu and Diamond 2005; van Oosterhout 2007; Australian Weeds Committee 2012; EPPO 2016
		USAqWRA Score	**74**		